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RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

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## RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

Research conducted in whole or in part under NASA Grant no. 377 includes theoretical and experimental radio and radar studies of lunar and planetary ionospheres, atmospheres, and surfaces, and radar studies of the sun and interplanetary medium.

### TECHNICAL PROGRESS

#### Planetary research

Planetary research has continued this period and the results will be published as a Ph.D. dissertation under the title, "Bistatic radar methods for studying planetary ionospheres and surfaces." The theory developed in this study has been applied to several cases as mentioned in the previous progress notes concerning Mariner and Pioneer programs.

On the next space probe mission to Mars, for example, JPL intends to use a 2300 Mc signal for telemetry. If the spacecraft is occulted by the Martian atmosphere, changes in amplitude and phase of the telemetry signal will be produced during the occultation. The results show that these effects can be used to determine characteristic properties of the lower atmosphere on Mars. Further work is being done on propagation and reflection problems associated specifically with Pioneer, AIMP, and future Mariner spacecraft.

## Propagation characteristics through the solar corona

An investigation was launched into the problem of measuring properties of the solar corona using radio transmissions from earth to a deep space probe. The first step in the investigation was to study propagation characteristics from the earth to various points in the solar corona.

The particular propagation characteristics considered were the phase path, group path, and absorption of the RF wave at 50, 100, and 400 Mc. Initially, a straight line approximation was made for the ray paths in calculating the above propagation characteristics. Appropriate assumptions were made regarding the electron density distribution in the solar corona. Results are presented in a series of curves of phase path defect (change in the phase path due to the presence of the solar corona as opposed to the phase path in free space) between the space probe and the earth. The curves were plotted as a function of the distance between the probe and the sun with the ray miss distance as a parameter. In this particular straight-line approximation case, a high frequency approximation was employed which gave the result that the phase advance equals the group delay. The attenuation of the wave due to electron-ion collisions was found to be very small.

Next, refractive bending of the rays was considered in the calculations of the different propagation characteristics. The calculations were performed on the Burroughs B5000 digital computer. Corresponding curves of

the approximate phase path defect, group path defect, and the absorption integral were plotted again as a function of the distance between the space probe and the sun with miss distance as a parameter.

The second step in the investigation is to study more closely the effect of severe ray bending on wave reception by the space probe. Severe refraction produced a significant change in the doppler shift from that of the direct ray as measured by the probe. Present efforts are being directed toward determining the magnitude of the doppler change.

The investigation conducted so far has assumed a spherically symmetric model of the solar corona. It is anticipated that this assumption will eventually be relaxed and sources of anisotropy such as solar streams and magnetic fields will be introduced.

Concurrently, publications pertinent to the investigation are being studied.

#### Solar radar program

In connection with the attempt at Stanford during the summer of 1963 to obtain radar echoes from the sun, the properties of maximal length sequences have been studied. Work has been completed on a maximal length sequence cross correlation program and the sub-routine for automatically plotting the correlation function. Consideration of other

solar radar results and progress of the solar cycle dictates a choice of sequence and interval length that will give the maximum probability of echo detection. This choice is made at the sacrifice of range resolution and can be easily changed on a day-to-day basis if echoes of sufficient strength are received.

A total of 62 solar radar runs were made. Of these 40 were felt to be of suitable, noise-free quality to warrant reduction to punched cards. All digitized data have now been run on the IBM 7090 and the individual runs plotted. From the extensive lunar work done before, during, and after the solar runs, confidence in the radar's performance is extremely high and the present system is considerably more sensitive than that used at Stanford in 1958-59, during the first successful detection of solar radar echoes. Since data reduction to this date has not indicated any echoes, it may be surmised that the solar cross section does indeed vary appreciably with the sunspot cycle (being maximum in 1958-59 and nearly minimum at the time of these later data).

Present efforts are being devoted to study of the non-stationary noise involved and refinement of the data processing to incorporate these findings.

### Cislunar gas studies

The two frequency moon radar experiment has been completely instrumented and can now run on a fairly routine basis. A 25-Mc, 300-kw signal is sent using the log periodic array and a 50-Mc, 50-kw signal is sent with the SRI 150-foot dish. Multiplying the 25-Mc doppler by two and subtracting it from the 50-Mc doppler cancels range rate and leaves only the effect of the propagating medium and the lunar surface. The choice of 25 and 50 Mc is such that the ionospheric effects in the result are about five times greater than the roughness due to libration. Diurnal changes in the earth's ionosphere are easily observable by this method, and the data are partially reduced in real time in order to detect at once any major changes in the medium.

During the 20 July 1963 solar eclipse, Stanford provided two frequency transmissions for the University of Illinois, AFCRL, and Penn State. The University of Illinois group, under the direction of George Swenson, Jr., supplied Stanford with receivers and goniometers to measure polarization changes. There were a total of seven remote stations, three of them along the path of totality.

Combining polarization and dispersive doppler measurements at Stanford has produced some very interesting

results. The eclipse at Stanford was 23 percent of the solar disc and by subtracting Faraday data on the eclipse day from those on the preceding day, an ionospheric decrease of  $2 \times 10^{16}$  elec/m<sup>2</sup> or about 15 percent of the total content can be seen. The maximum depression occurred 45 minutes after eclipse maximum and this time agrees well with F-region attachment rates.

Of even more interest is the result obtained when Faraday data are subtracted from doppler data. The control day indicates that all changes are occurring in the ionosphere while a  $3.4 \times 10^{16}$  elec/m<sup>2</sup> depression on the eclipse day can only be interpreted as a change above the ionosphere. If this change were in the magnetosphere, say to 13 earth radii, it would mean about a 50 percent depression in magnetospheric content. Whistler data for the period were quite good and a detailed analysis by Prof. R. A. Helliwell's group has shown that a maximum depression of 20 percent in magnetospheric content could have occurred, but the probability is that it was much less.

Based on these two different measurements, it is felt that the depression occurred both above the earth's ionosphere and beyond 6 earth radii. If this is the case, the change amounts to some 75 electrons per cc over the remaining earth-moon path. This is an order of magnitude greater than the maximum solar wind density as measured

by several space probes and is such a startling result that it is hoped future measurements using the present equipment will be possible through several lunations. To make rapid data reduction possible, a computer program has been developed which scales doppler, Faraday, and the two signal strength channels simultaneously. These data are put on punched cards by the IBM 1620 located in the Electronics Laboratory and the cards are then processed by the University IBM 7090. The output is a plot of Faraday, doppler, and the integrated doppler. At the same time the digital data are transferred to magnetic tape, providing convenient future access for further computation.

Since the 20 July 1963 eclipse, the 25 and 50 Mc Faraday antennas have been moved to a site 800 meters from the transmitter building. Details of the transmissions are the same with 50 kw on 50 Mc, using the SRI 150-foot dish, and 300 kw on 25 Mc, using the log-periodic array. Transmitted polarizations are linear and receiving is done with both the transmitting antennas and separate, crossed Yagis. The crossed Yagis are located at the SRI 60-foot dish site and the 50-Mc antennas are mounted in that dish. This change gives a signal-to-noise ratio improvement of 12 db on the 50-Mc Faraday



channel over the arrangement used during the eclipse. Computer scaling is now possible, for signal strengths are adequate and, through the use of phone lines, all data are recorded on the same magnetic tape simultaneously.

Operation of the equipment has been on a six day per week basis since mid-December and is expected to continue through March in an attempt to observe four full lunations. Analysis of the data at this writing is about one month behind the daily radar runs, but should be up-to-date by the end of March.

This early analysis has shown several interesting and unexpected things through comparison of doppler and Faraday data. First, the two measurements agree fairly well during the daytime hours, suggesting that the density variation between the earth and moon is occurring nearly entirely in the earth's ionosphere. This is not true during the nighttime hours and the lower ionosphere becomes stable in much the way indicated by vertical-incidence sounders and satellite measurements while the remaining earth-moon path varies in a manner suggesting large scale irregularities at great heights. Second, the fluctuations in columnar density as observed by the two measurements nearly always shows a time difference. The fact that the two receiving sites are separated by 800 meters may make it possible to determine the altitude, size, velocity, and density of the irregularities in the ionosphere.